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DOI: <https://doi.org/10.1024/0036-7281/a000499>

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ZORA URL: <https://doi.org/10.5167/uzh-80164>

Journal Article

Accepted Version

Originally published at:

Wyss, F; Wenker, C; Hoby, S; Gardelli, B; Studer-Thiersch, A; von Houwald, F; Schumacher, V; Clauss, Marcus; Doherr, M G; Häfeli, W; Furrer, S; Béchet, A; Robert, N (2013). Factors influencing the onset and progression of pododermatitis in captive flamingos (*Phoenicopteridae*). *Schweizer Archiv für Tierheilkunde*, 155(9):497-503.

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Factors influencing the onset and progression of pododermatitis in captive flamingos (*Phoenicopteridae*)

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Summary

15 Pododermatitis is a worldwide problem in captive flamingos. We performed an evaluation of
 different influence factors (age, sex, weight, origin, breeding status) and a comparison of foot
 lesions between several zoological institutions and the feet of free-ranging Greater flamingos
 (*Phoenicopus roseus*). A scoring system was used to determine the prevalence and types of
 lesions and severity. Cracks and nodules were developed as early as 3 months of age and
 20 papillomatous growths as early as 6 to 7 months of age in captivity. Nodules with ulceration
 occurred significantly more often in birds older than 31 years and heavier than 4 kg. The
 comparison of different institutions revealed that birds kept in enclosures with natural-floored
 water ponds had significantly less severe lesions than birds kept in concrete water ponds. None
 of the free-ranging flamingos, which live on a muddy underground, showed any lesion. This
 25 study demonstrates that flooring, weight and age are important in the onset and progression of
 pododermatitis in flamingos.

Keywords: bumble foot, flamingo, foot lesion, *Phoenicopteridae*, pododermatitis

Einflussfaktoren für die Entstehung und Entwicklung von Pododermatitis bei in 35 Gefangenschaft gehaltenen Flamingos (*Phoenicopteridae*)

Pododermatitis ist weltweit ein Problem von in Menschenobhut gehaltenen Flamingos. In dieser Studie wurden verschiedene Einflussfaktoren (Alter, Geschlecht, Gewicht, Herkunft, Brutstatus) untersucht und ein Vergleich der Fussläsionen von mehreren Flamingohaltungen untereinander sowie mit den Füßen von freilebenden Rosaflamingos (*Phoenicopus roseus*)
40 durchgeführt. Prävalenz und die verschiedenen Typen der Fussläsionen sowie ihr Schweregrad wurden anhand eines Kriterienkataloges bestimmt. Risse und Knoten entwickelten sich bereits bei 3 Monate alten Tieren; papillomatöse Zubildungen wurden erstmals bei 6 bis 7 Monate
alten Flamingos gesehen. Knoten mit zentraler Ulzeration wurden signifikant häufiger bei über
45 31 Jahre alten sowie bei über 4kg schweren Flamingos gefunden. Flamingos in Gehegen mit Naturboden-Teichen hatten weniger und geringgradigere Fussläsionen als Flamingos in Gehegen mit Betonboden-Teichen. Bei keinem der freilebenden Rosaflamingos, die auf einem lehmigen Untergrund leben, wurden Fussveränderungen gefunden. Diese Studie zeigt, dass
Untergrund, Gewicht und Alter eine Rolle in der Entstehung und Entwicklung der
50 Pododermatitis bei in Menschenobhut gehaltenen Flamingos spielen.

Schlüsselwörter: Bumblefoot, Flamingo, Fussläsion, Phoenicopteridae, Pododermatitis

Introduction

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The family *Phoenicopteridae* consists of six different species. The largest species is the Greater flamingo (*Phoenicopus roseus*), weighing approximately 3.4 kg (Johnson und Cézilly, 2007). Flamingos are among the longest-living birds indicated by five 59-years old captive Greater flamingos still kept in Zoo Basel to date.

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Pododermatitis was the most prevalent finding diagnosed in captive flamingos sent to the Institute of Animal Pathology Bern between 2000 and 2010. Up to 100% of the captive European and North American flamingo population (20 zoos) suffer from varying degrees of foot problems (Nielsen et al., 2010). Foot problems also occur frequently in raptors, cockatiels and penguins (Reidarson et al., 1999, Harcourt-Brown, 2008) but rarely in free-ranging birds (Herman et al., 1962, Gentz, 1996, Kummrov et al., 2010). In raptors, the classic bumblefoot lesion is a nodule with a central ulceration, mostly on the base of the foot (Kummrov et al., 2010). In flamingos, this is only one of the four distinguished lesions that include hyperkeratosis, cracks, nodules and papillomatous growths (Nielsen et al., 2010).

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Flamingos living north of the 53rd degree of latitude, in colder regions and kept mostly indoors have a special risk to develop pododermatitis (Nielsen et al., 2012). It seems that type and humidity of flooring, available space or and the feeding regime, which all differ between indoor and outdoor enclosures, are associated with the prevalence of pododermatitis.

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The Zoo Basel has kept Greater flamingos since 1932, and foot lesions have been observed for a long time. The aim of this study was to evaluate possible influencing factors like sex, age, weight, origin and breeding status, and to compare foot lesions of the flamingos of Zoo Basel with those from other zoos in Switzerland and France, as well as with those of free-ranging flamingos in the Camargue, France.

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Animals, Material and Methods

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Animals

In this study, 291 captive Greater and Chilean (*P. chilensis*) flamingos from 4 different institutions in Switzerland and France were examined. Institutions were chosen depending on availability of birds for routine operations like ringing or wing clipping. The flamingos from Parc des Oiseaux were divided into 2 groups: one consisting of parent-reared birds (n=15), one of hand-reared birds (n=13) and birds with unknown rearing regime (n=16). The feet of one

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adult and 48 juvenile free-ranging Greater flamingo in the Camargue were examined during yearly routine capture activities in August 2010 and July 2011, when young (3 months old) birds were ringed, weighed and measured (Johnson und Cézilly, 2007). These operations were supervised by the Tour du Valat Research Center, France and took place at the Etang du Fangassier breeding site (43°25'N, 4°38'E). Additionally, the feet of 10 adult free-ranging Greater flamingos from the Camargue, which were found dead, were examined.

Exhibits

The exhibit in Zoo Basel houses 129 Greater flamingos, and measures about 2000 m² including 425 m² of shallow water ponds with concrete flooring (max. depth: 25 cm), 135 m² of deep water ponds with a natural mud ground (max. depth: 200 cm), two breeding islands (25 m² and 35 m²), grass resting sites and a marsh area. A winter house (94 m²) with a concrete floor is integrated in the exhibit . One half of this floor is covered with black rubber mats used for cattle, offering sufficient resting space for all birds, and the other half consists of two water ponds with concrete floor (25m² and 10m², max. depth: 40 cm).

The exhibit in Zoo Zurich houses 49 Chilean flamingos, measures about 900 m² and includes two ponds. One of them has natural flooring (approx. 80 m², depth: 10-20 cm); the other has concrete flooring (approx. 72 m², max. depth: 150 cm) and contains a feeding area (circular, approx. 3 m²). The area around the ponds is covered by natural grass.

The exhibit in Tierpark Dählhölzli, Bern, houses 69 (among them 6 juveniles) Greater flamingos, measures about 1000 m², and includes one big water pond of about 920 m². The pond flooring is made of concrete and covered with 10 cm of sand. The depth of the water varies from 30 to 50 cm in three quarters of the pond, and one quarter is up to 150 cm deep.

The exhibit in Parc des Oiseaux, Villars-les-Dombes, France, houses 44 Chilean flamingos, and measures 1750 m², consisting mainly of a 1200 m² water pond with natural ground (mud), which is 20 to 80 cm deep. The area around the pond consists of mud and sand. The hand-rearing unit is in a separate building with a concrete floor.

Examination of the feet

The feet of all flamingos were examined and foot lesions were recorded during routine capture operations, and photographs were taken. Flamingos from Zoo Basel were evaluated in winter 2009/2010, and birds from all other institutions were evaluated in fall/winter 2010. Juvenile flamingos hatched in May/ June 2010 in Zoo Basel were examined in August 2010 (n = 21) at

120 the age of 2.5 to 3 months. For these juveniles, photographs of the feet were taken, and lesions were evaluated from these photographs only.

Nielsen et al. (2010) classified flamingo foot lesions into four types with two subtypes each: slight overgrowth/marked overgrowth (hyperkeratosis), superficial cracks (CRs 1) and deep cracks (CRs 2), nodules without ulceration (NLs 1) and nodules with ulceration (NLs 2), finger-like papillomatous growths (PGs 1) and cauliflower-like papillomatous growths (PGs 2). In this study, the classification of hyperkeratosis was not used because there was no age-matched control of a normal foot, and because Nielsen et al. (2010) found that the prevalence of hyperkeratotic lesions is about 100%. The prevalence (at least one lesion of one type on one of the feet) was determined for all lesions. The total of locations affected by one subtype was also calculated and analyzed, but because these results did not differ from those obtained using the prevalence as described above, they are not presented. Additionally, each pair of feet was classified from grade 0 to 5 to evaluate the severity of the disease independent of the type of lesion (Tab. 1). The classification of lesions was performed on site in Zoo Basel and Tierpark Dählhölzli Bern, whereas in Zoo Zurich and Parc des Oiseaux, classification was evaluated only later from photographs. Severity was always scored by photographs. All evaluations were carried out by the first author.

Data collection: age, sex, weight, origin, breeding status (Zoo Basel)

Age, sex and origin were obtained from existing records for 129 birds from Zoo Basel. All birds were weighed during the routine capture. Data on breeding activity was collected from observations during the breeding season. Definitions of groups are given in Table 3. Concerning the origin of the birds, the place of hatching was considered. Birds whose origin was not documented were excluded. All birds that bred successfully (chick hatched) were classified as “Successful”. The “Not Successful” (n = 32) group was composed of flamingos which had an egg, but did not brood for more than 14 days, and no chick hatched. The group “No Breeding” (n = 24) was composed of birds that did not show any breeding activity. The young, not yet sexually mature (less than three years old) birds were excluded from the evaluation of this factor.

Statistical analyses

The effects of factor variables such as zoos, age groups, sex, weight groups, origin and breeding status on severity scores and on the total of affected locations by one subtype were assessed using Kruskal-Wallis One-Way ANOVA and the Kruskal-Wallis Multiple-Comparison Z-

Value Test (Dunn's Test). Associations between categorical variables such as prevalence of cracks, nodules and papillomatous growths and factor variables such as zoos, age groups, sex, weight groups, origin and breeding status were assessed using Chi-Square and Fisher's Exact Test, depending on the number of classes. Statistics were performed in NCSS 2007 (www.ncss.com). The level of statistical significance was 0.05.

Results

Comparison of different institutions and free-ranging flamingos

All types of previously described lesions (hyperkeratosis, cracks, nodules, papillomatous growths) were observed in zoo flamingos, although hyperkeratosis was not scored. The severity differed significantly among zoos ($p < 0.001$), being the lowest at Zoo Zurich (0.6 ± 0.6), followed by Tierpark Dählhölzli (1.0 ± 0.9) and Parc des Oiseaux (2.1 ± 1.2) and the highest at Zoo Basel (2.9 ± 1.2). Prevalence estimates for most of the outcomes were highest in Zoo Basel, followed by Tierpark Dählhölzli and Parc des Oiseaux. Zoo Zurich was among the lowest in every category (Tab. 2). Around half of the juvenile Greater flamingos from Zoo Basel had already developed superficial and deep cracks (CRs 1+2) as well as nodules without ulceration (NLs 1) when scored at about 3 months. No lesions were detected in any of the free-ranging juvenile or adult flamingos.

Potential influence factors (Table 3)

Birds older than 31 years showed an increased prevalence of nodules with ulceration (NLs score 2) compared to the other age groups ($p = 0.009$). Birds younger than 1 year suffered significantly less ($p < 0.001$) from papillomatous growths (PGs score 1 and 2) than all other age groups. Males suffered significantly more often from nodules without and with ulcerations than females ($p = 0.012$ for NLs score 1 and 2 and $p = 0.001$ for NLs score 2). Nodules with ulceration (NLs 2) were also significantly more prevalent ($p < 0.001$) in birds weighing more than 4 kg compared to birds weighing less than 4 kg. In general, the comparison between birds that did or did not breed successfully or did not breed at all revealed no significant differences. Concerning the bird's origin, significantly less deep cracks (CRs score 2) were noted for wild-caught animals compared with animals hatched in zoos ($p < 0.001$). Flamingos hatched in Zoo Basel were 10.3 ± 12.1 years old and weighed 3.4 ± 0.8 kg. Flamingos hatched in another zoo

than Zoo Basel were 6.0 ± 3.3 years old and weighed 3.3 ± 0.7 kg. Wild-caught flamingos were 20.5 ± 18.3 years old and weighed 3.3 ± 0.6 kg.

Discussion

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Compared with the average of 20 zoos in Europe and North America (Nielsen et al., 2010), the prevalence of score 2 lesions was higher for all the types at Zoo Basel and Parc des Oiseaux and lower at Zoo Zurich and Tierpark Dählhölzli. Foot problems in flamingos affect all age groups and may develop at a very young age, as early as 2.5 months old. It became evident that husbandry, especially flooring, is an important factor in the onset of this disease, because no lesion was found in free-ranging flamingos and less lesions were found in flamingos kept on soft flooring.

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Comparison of foot lesions among different flamingo species (Greater and Chilean flamingos) seems appropriate, because no pattern was found between foot lesions and flamingo species in a study with 929 flamingos (Nielsen, 2008). Even if always performed by the same person and if types of lesions were categorized, the evaluation still remained partly subjective. Evaluation of lesions from photographs is challenging since palpation of the feet is sometimes required for accurate classification, especially for nodular lesions (Nielsen et al., 2010). Therefore, results from animals scored from photographs only at Zoo Zurich and Parc des Oiseaux could be biased. The higher prevalence in our study compared with Nielsen et al. (2010) could thus be due to higher scores in our study when feet were palpated, whereas Nielsen et al. always scored by photographs. It is important to emphasize that free-ranging Greater flamingos in the Camargue did not show any lesions. These flamingos live in lagoons, whose flooring is composed of very soft mud.

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Individual captive flamingos already had cracks and nodules without ulceration at the age of 2.5 months. At the age of about 6 months, 100% of the birds had already developed cracks (CRs 1+2), and 86% suffered from nodules (NLs 1 + 2). Papillomatous growths (PGs 1 + 2) were found latest in the course of the disease. Only 2 out of 21 juveniles had developed papillomatous growths at the age of 6 months. We therefore hypothesize that papillomatous growths start to develop at about 6 months whereas cracks and nodules already develop earlier.

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A healthy development in juvenile flamingos appears important to prevent or at least limit the development of foot lesions later: Originally wild-caught birds had the lowest severity, and especially cracks were significantly lower in this group. In contrast, wild-born falcons living in

captivity are significantly more prone to develop bumble foot than their captive-bred counterparts (Müller et al., 2000). In growing turkeys, even a short time frame on a suboptimal flooring (e.g. 8 hours per day) was sufficient for the development of foot pad dermatitis (Youssef et al., 2011). Flamingos born in the wild grow up on smooth natural flooring and develop healthy feet. Therefore, they may be less susceptible to foot lesions when kept on rough artificial flooring later in their life. Flamingos which grew up in the hand-rearing unit at Parc des Oiseaux on concrete flooring 1 or 2 years before the evaluation still had a higher severity and higher prevalence of all lesions in winter 2010 than the rest of the group which was kept in an enclosure with natural mud flooring. The importance of flooring becomes even more evident when comparing different zoos. A significantly lower severity and prevalence for almost all types of lesions were noted for Zoo Zurich and Tierpark Dählhölzli, compared to Zoo Basel. In Zoo Zurich, the enclosure consisted of a concrete and a natural floored water pond, but the latter was the one mostly used, and in Tierpark Dählhölzli, a big concrete water pond is covered with 10 cm of sand. Intermediate between these two zoos and Zoo Basel, Parc des Oiseaux's higher severity and prevalence can be partially explained by the hand-rearing of several birds on concrete flooring as mentioned above. Zoo Basel had the highest overall severity and prevalence, probably at least partly due to its concrete-floored water ponds in the outdoor enclosure. We hypothesize that the rough surface of the concrete flooring in Zoo Basel and in the hand-rearing unit of Parc des Oiseaux is responsible for repeated small mechanical injuries that may extend into different types of pododermatitis.

Increased weight and suboptimal perching surfaces are factors in the development of bumblefoot in captive raptors (Kummrov et al., 2010) and penguins (Reidarson et al., 1999). Nodules with ulceration (NLs score 2) are the most similar to the classic bumblefoot lesions. It is therefore not surprising that heavy animals suffer significantly more from this type of lesion than those weighing less. Taken into account that wild Greater flamingos weigh approximately 3.4 kg, dietary measures for zoo flamingos may be considered. In our study, old birds had a higher prevalence of nodules with ulceration (NLs score 2) than younger birds; it can be suggested that this is an accumulation of the factors described above, standing on rough flooring for a long time. In contrast to a study conducted in a British facility where flamingos producing fertile eggs had the highest mean bumblefoot scores (Taylor, 2003), no differences were seen between any of the breeding status groups in our study. It seems that foot lesions do not detain birds from breeding. Further studies are warranted in order to better understand the etiology of pododermatitis in flamingos and to evaluate a possible contribution of malnutrition and other factors to this multifactorial disease. The results of this study led to the performance

of (successful) trials regarding the use of finely granular sand as substrate, and may help to improve the foot health of flamingos in captivity.

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Acknowledgements: The authors acknowledge the staff of the Zoo Basel, especially the responsible keeper for the flamingos, Bruno Gardelli, and the staff from Parc des Oiseaux in Villars-les-Dombes, Zoo Zurich and Tierpark Dählhölzli Bern for their valuable cooperation.

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Table 1: Criteria for scoring the severity of skin lesions in flamingo feet.

Grade / Criteria	Total No of lesions (on both feet)	No of NLs and PGs (on both feet)	Diameter of NLs and PGs	Type of NLs
Grade 0	no lesions at all			
Grade 1 = mild	< 10	1-2	< 1 cm	without ulceration
Grade 2 = mild to moderate	< 15	1-2	< 1.5 cm	without ulceration
Grade 3 = moderate	< 15	< 3	< 2.5	without/with ulceration
Grade 4 = moderate to severe	< 20	< 3	< 3 cm	with ulceration
Grade 5 = severe	more than 15	3 and more	3 cm and more	with ulceration

NLs = Nodules, PGs = Papillomatous growths

- 295 Table 2: Mean (\pm SD) severity of foot lesions and prevalence of respective scores (1+2 or 2) for cracks, nodules and papillomatous growths of flamingos from different zoos in Switzerland and France in comparison to the study of Nielsen et al. (2010).

	Zoo Basel, 09/10	Zoo Zürich, 2010	Tierpark Dählhölzli 2010	Parc des Oiseaux 2010	Nielsen et al. 2010
No of birds	129	49	69	44	929
Severity \pm SD	2.9 ± 1.2^a	0.6 ± 0.6^b	1.0 ± 0.9^b	2.1 ± 1.2^c	--
Prev. CRs 1+2	96% ^a	56% ^b	36% ^c	95% ^a	87%
Prev. CRs 2	86% ^a	19% ^b	25% ^b	66% ^c	46%
Prev. NLs 1+2	76% ^a	21% ^b	88% ^a	68% ^c	17%
Prev. NLs 2	26% ^a	2% ^b	14% ^c	23% ^{ac}	4%
Prev. PGs 1+2	77% ^a	0% ^b	4% ^b	39% ^c	46%
Prev. PGs 2	56% ^a	0% ^b	1% ^b	30% ^c	12%

CRs = Cracks, NLs = Nodules, PGs = Papillomatous growths

^{a,b,c} Within each row, means with different lower-case superscript differ significantly ($p < 0.05$)

- 300 from each other

Table 3: Influence of age, sex, weight, origin and breeding on severity and prevalence of foot lesions of captive Greater Flamingos from Zoo Basel.

Factor		No	Severity	Prev. CRs 1+2	Prev. CRs 2	Prev. NLs 1+2	Prev. NLs 2	Prev. PGs 1+2	Prev. PGs 2
Age	<1year	21	1.8 ± 0.7 ^a	100%	95%	86%	19% ^{Aa}	10% ^{Aa}	5% ^{Aa}
	1-5 years	38	2.6 ± 1.1 ^{ab}	97%	82%	76%	18% ^{Aa}	89% ^{Bbc}	50% ^{Bb}
	6-10 years	18	3.2 ± 0.9 ^{bc}	89%	89%	83%	17% ^{Aa}	100% ^{Bb}	78% ^{Bc}
	11-20 years	23	3.7 ± 1.1 ^c	91%	78%	87%	30% ^{ABa}	87% ^{Bbc}	83% ^{Bc}
	21-30 years	16	2.9 ± 1.3 ^{bc}	100%	88%	75%	25% ^{ABa}	94% ^{Bbc}	69% ^{Bbc}
	>30 years	13	3.6 ± 1.0 ^{bc}	100%	92%	92%	69% ^{Bb}	77% ^{Bc}	62% ^{Bbc}
Sex	Female	65	2.7 ± 1.1	94%	83%	74% ^{Aa}	14% ^{Aa}	75%	54%
	Male	64	3.0 ± 1.3	98%	89%	91% ^{Ab}	39% ^{Bb}	78%	58%
Weight	< 3 kg	38	2.8 ± 0.9	95%	84%	82%	26% ^{ABa}	68%	53%
	3-4 kg	65	2.8 ± 1.2	97%	88%	78%	14% ^{Aa}	78%	54%
	>4 kg	26	3.2 ± 1.4	96%	85%	92%	58% ^{Bb}	85%	65%
Breeding status	successful	43	3.2 ± 1.2	98%	84%	84%	30%	88%	79%
	not successful	32	2.9 ± 0.9	91%	84%	81%	22%	91%	75%
	no breeding	24	3.2 ± 1.2	96%	83%	83%	33%	88%	71%
Origin	wild born	32	2.5 ± 1.0	94%	66%	84%	38%	75%	47%
	zoo born (Zoo Basel)	80	3.0 ± 1.3	99%	94%	79%	25%	74%	61%
	zoo born (other zoo)	15	2.7 ± 0.9	93%	93%	93%	13%	93%	47%

CRs = Cracks, NLs = Nodules, PGs = Papillomatous growths

A,B, C, a,b,c Within a column and a group, means with different superscript differ significantly (upper case letters for p < 0.01; lower case letters for p <

305 0.05) from each other; absence of superscript indicates no significance

Figure 1: Severity of foot lesions in free-ranging (grade 0) and captive flamingos (grades 1 – 5).

